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AGE, ALTITUDE, AND WORKLOAD EFFECTS ON COMPLEX PERFORMANCE

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16. Abstract Fifteen healthy men in each of three age groups, 20-29 yrs, 40-49 yrs, and 60-69 yrs, were evaluated regarding complex performance in two altitude conditions (ground level vs. 3,810 m) which were administered during performance testing. Performance was measured during a 3-h test session with the Multiple Task Performance Battery (MTPB) which involved time-shared performance of several flight-related tasks presented in different combinations to vary workload. MTPB tasks consisted of monitoring of warning lights and meters, mental arithmetic, problem solving, visual target identification, and tracking. Heart rate decreased slightly at the 3,810 m altitude in the 60-69 yr group, but increased significantly at altitude in the two younger groups. Both epinephrine and norepinephrine excretion rates were highest in the 20-29 yr group and lowest in the 40-49 yr group. Epinephrine excretion rate was significantly higher at altitude in all age groups, but that was not the case with norepinephrine excretion rate. Urinary 17-ketogenic steroid excretion rate and Fatigue Check List responses yielded no significant effects of either age or altitude. Complex (time-shared) performance of MTPB tasks decreased with age. Age related decrements occurred in monitoring tasks, information-processing tasks, and a tracking task involving psychomotor-coordination. Performance differences occurring as a function of age were evident predominantly at moderate and high workload levels. There were no important effects of altitude on performance. Physiological and biochemical responses had little relation to performance. Implications of these findings for future research relating age to pilot performance are discussed.

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Aviation environment, Simulation, Age, Complex performance, Workload

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Age, Altitude, and Workload Effects on Complex Performance

Introduction

Recent reviews of the literature on aging and pilot performance have pointed to the paucity of research investigating the relation of age to perceptual, cognitive, and intellectual functions of pilots (10,15). Although many laboratory studies of the relation of age to performance have shown age-related declines in tasks involving such functions as perceptual-motor reaction time, speed of visual processing, memory, and problem solving (2,4,6,10,12,14,15,23,24,25,28), most of these experiments were not controlled for health of subjects and it is difficult to generalize their findings to pilots who, as a group, are highly selected and controlled for health. The research of Szafran (24,25), who employed actual pilots as subjects, has shown that workload may be a critical factor in studies that attempt to relate age to pilot performance of flight-related tasks. He found no performance deficits as a function of age in a serial-choice reaction time task performed by itself. Only when workload was increased by requiring simultaneous performance of a short-term memory task did age effects appear. Workload-induced performance decrements were found to increase with age in pilots under age 60.

The importance of the interaction of age with workload is corroborated by single task studies involving nonpilots who have shown age-related performance decrements only when task difficulty or workload was increased by varying such factors as signal rate in vigilance tasks or complexity of a problem solving task (5,24,25,26,27). The above findings concerning the age/workload interaction suggest that future research on aviation stressors, which may interact with age, should include workload as a controlled variable. The work of Szafran (24,25) discussed above, and several studies in which the time-sharing performance of pilots in the laboratory was shown to be predictive of actual flight performance (7,11,22), also suggest that measurement of time-shared performance of flight-related tasks may be particularly appropriate for study of age-related effects of aviation stressors.

The Civil Aeromedical Institute's Multiple Task Performance Battery (MTPB) measures time-shared performance on several flight-related tasks. The present research was conducted to evaluate the utility of the MTPB as a tool for future age-related research. It was expected that workload-induced performance decrements would increase with age and that performance might not differ between age groups in low-workload conditions.

In this study, the physiological condition and intellectual ability of subjects in different age groups was controlled by requiring that all subjects pass the equivalent of a Class III airman's physical examination, exhibit pulmonary function in the normal range, and have an intelligence quotient (IQ) in the normal range or above.

Method

Subjects. Forty-five subjects, fifteen in each of three age groups, 20-29 yrs, 40-49 yrs, and 60-69 yrs, were evaluated. These subjects passed the equivalent of a Class III airman's physical examination including simple blood and urine tests, and had pulmonary function within the normal range; i.e., measurements were greater than 80 percent of the predicted normal values (21) regarding forced vital capacity, forced expiratory volume (1-s and 3-s), peak flow, and forced expiratory flow for the middle half of forced expiratory volume. All subjects also had intelligence in the normal range or above as measured by the Shipley Institute of Living Scale and four subtests of the Wechsler Adult Intelligence Scale (vocabulary, information, block design, and picture completion). With the exception of four subjects in the 60-69 yrs group, subjects were free of chronic disease and not taking medication. The exceptions were three subjects who were successfully being treated for hypertension whose blood pressure and other physiological measurements were within the normal range. A fourth subject exhibited a trace of sugar in a urine test, but had no other symptoms.

Procedure. Following 15 hours of training on the MTPB, 3 hours on each of 5 successive days, the subjects performed in two 3-h experimental sessions, one at ground level and one at a simulated altitude of 3,810 m (12,500 ft). The two experimental sessions were separated by 2 days and the order of conditions was reversed in approximately half the subjects. Altitude simulation was accomplished by gas mixtures administered through face masks worn by the subjects. During each 3-h experimental session the subjects performed on the MTPB for three consecutive 56-min periods. The MTPB included time-shared performance in vigilance (monitoring of green and red warning lights and meters), problem solving, mental arithmetic, visual target identification, and tracking tasks. These tasks have been described in detail elsewhere (13,16). Four workload intervals occurred in each period, i.e., in four successive 14-min intervals. All intervals involved monitoring of warning lights and meters. The first interval (low workload) included target identification in addition to monitoring. The second interval (high-moderate workload) included target identification and problem solving in addition to monitoring. The third interval (low-moderate workload) included mental arithmetic, tracking, and monitoring. The fourth interval (high workload) included mental arithmetic, tracking, problem solving and monitoring.

Several physiological and biochemical measurements were made during the two test sessions. The urine formed during each 3-h experimental session was collected and urine samples were analyzed for epinephrine, norepinephrine, and 17-ketogenic steroids. Heart rate (HR) was recorded continuously during each 3-h session.

Performance was assessed in terms of composite scores for each task. Composite scores summarized all measures of performance for the particular task. An overall composite score (all tasks) was also obtained. Task composite scores were calculated as follows: for each measure of performance on a task, the raw scores for all subjects were converted to standard scores with a mean of 500 and a standard deviation of 100. The

task composite score for each subject and experimental treatment was the mean of standard scores on each performance measurement. The sign of scores was changed, when necessary, so that higher standard scores always indicated better performance and lower scores, poorer performance. An overall composite score was also calculated for each subject and each treatment by averaging the composite scores for different tasks so that each task made an equal contribution to the variance. Analyses of task and overall composite scores were made because they: (i) simplify the evaluation of a large amount of data; (ii) have been found to be more sensitive to the effects of experimental conditons than the individual measurements of performance; and (iii) have higher reliability than raw score data on individual performance measures (16).

On experiment days, subjects reported to the laboratory at 0830. Each subject emptied his bladder as completely as possible without collection of urine. The time was recorded and urine was subsequently collected at the end of each experiment. The volume was recorded and a portion of the sample was frozen for later analysis of catecholamines and 17-ketogenic steroids. The subjects were then fitted with adhesive chest electrodes which were connected to an electromagnetic tape recorder for continuous HR recording. At 0900 subjects donned face masks and the performance testing was begun. Each subject filled out a Fatigue Check List (FCL) prior to and following both test sessions.

Results

All data were treated by analysis of variance techniques.

Physiological and Biochemical Responses. The effects of age and altitude on heart rate, urinary excretion rates for epinephrine, norepinephrine, 17-ketogenic steroids, and FCL responses are shown in Table 1.

At the 3,810 m altitude, the mean heart rate over the 3-h experimental session was higher than at ground level in the two younger groups. Heart rate decreased slightly at altitude, as compared to ground level, in the 60-69 yr group. The interaction of age with altitude was statistically significant ($p < .02$) for heart rate data.

Epinephrine excretion rate data yielded a significant ($p < .01$) main effect of age and a significant ($p < .01$) main effect of altitude, but the interaction of age and altitude was not significant. Excretion rate was highest in the 20-29 yr group, and lowest in the 40-49 yr group. Excretion rate was consistently higher for all groups at the simulated 3,810 m altitude than at ground level.

Norepinephrine excretion rates manifested a significant main effect of age ($p < .01$) and a significant interaction of age and altitude ($p < .03$). At both ground level and a simulated altitude of 3,810 m, excretion rate was lowest in the 40-49 yr age group. At ground level, excretion rate was highest in the 20-29 yr group, and at 3,810 m excretion rate was highest in the 60-69 yr group.

Table 1. Physiological and Biochemical Measurements and Fatigue Check List Responses as a Function of Age and Altitude

Heart Rate (beats per min)

	Age (yrs) 20-29		40-49		60-69	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ground Level	77.5	7.2	78.5	15.1	85.3	19.1
3,810 m	84.9	10.9	82.6	12.7	82.0	16.1

Epinephrine (ng/h)

	Age (yrs) 20-29		40-49		60-69	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ground Level	2314	959	1444	684	1695	715
3,810 m	2962	1050	1577	728	2028	900

Norepinephrine (ng/h)

	Age (yrs) 20-29		40-49		60-69	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ground Level	5688	2323	4451	2146	4956	1827
3,810 m	5219	1886	3931	1451	7375	4526

17-ketogenic steroids (mg/h)

	Age (yrs) 20-29		40-49		60-69	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ground Level	.550	.165	.520	.221	.729	.710
3,810 m	.553	.174	.597	.346	.542	.327

Fatigue Check List Score

	Age (yrs) 20-29		40-49		60-69	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ground Level	12.4	2.8	12.2	3.7	11.1	3.3
3,810 m	12.6	2.9	11.9	4.7	11.4	3.2

Urinary 17-ketogenic steroid excretion rates and FCL responses yielded no significant effects of either age or simulated altitude.

Complex Performance. The overall and individual task composite score data (means and standard deviations) are shown for the main effects of age, altitude, period, and workload in Table 2 and Table 3. Since all tasks did not occur at all workloads, overall composite scores were averaged over workload conditions. Overall performance declined with age. Although the performance of the 40-49 yr group was not significantly less than the 20-29 yr group, performance in the 60-69 yr group was significantly ($p < .01$) less than in both the younger groups. Performance was also consistently lowest in all individual tasks in the 60-69 yr group, and significantly so in the case of monitoring of green ($p < .01$) and red ($p < .05$) lights, problem solving ($p < .01$) and tracking ($p < .01$). Altitude had little effect on performance as measured by overall composite scores or individual task composite scores, with the exception of the monitoring of red lights. Performance in the latter case was significantly ($p < .05$) higher at 3,810 m than at ground level, but that effect was small relative to the effect of age. Overall performance in successive 1-h periods of experimental sessions tended to be highest in Period 3 and lowest in Period 2. Although that tendency was slight, the main effect of period was statistically significant ($p < .05$). In the composite score data for individual tasks, the effect of period was statistically significant only in the cases of problem solving, mental arithmetic, and tracking. For problem solving and mental arithmetic, performance was again highest in Period 3. In the tracking task, performance consistently declined across successive periods.

The main effect of workload was statistically significant in all MTPB tasks as shown in Table 3. The workload variable was significant at the $p < .01$ level in monitoring of green lights, meters, target identification, mental arithmetic, and tracking, and at the $p < .05$ level in monitoring of red lights and problem solving. The workload variable will be considered in greater detail below in the context of the interaction of age with workload. The three monitoring tasks tend to be given lower priority than other MTPB tasks which require more active participation. The monitoring tasks, therefore, generally have secondary status and provide an index of residual attention inversely related to workload.

The pattern of main effects in monitoring performance indicates that task demands (workload) were highest (and monitoring performance lowest) in Workload 4 with Workloads 2, 3, and 1 following in that order. That order is in general accord with the number of tasks presented in each interval.

Interactions. The interaction of age with workload is shown for all tasks in Table 4. There was a significant interaction of age with workload in four tasks including all three monitoring tasks, green lights ($p < .01$), red lights ($p < .01$), and meters ($p < .01$), and in target identification ($p < .01$). The decrease in performance on these tasks with increasing workload was smallest in the 20-29 yr group and greatest in the 60-69 yr group. That trend, although not statistically significant, is also apparent in problem solving and mental arithmetic.

Table 2. Main Effects of Age and Altitude for Overall Composite Scores and Composite Scores for Individual Tasks

		AGE (yrs)			ALTITUDE	
		20-29	40-49	60-69	Ground Level	3,810 m
Overall	Mean	522.9	512.2	465.9**	499.9	500.8
	S.D.	48.5	39.6	45.3	55.4	47.2
Green Lights	Mean	547.1	522.2	430.7**	500.4	499.6
	S.D.	78.4	75.2	103.2	97.8	102.1
Red Lights	Mean	510.3	521.9	467.8*	494.6	505.4*
	S.D.	95.1	58.6	126.0	109.0	89.6
Meters	Mean	518.5	504.2	477.3	497.4	502.6
	S.D.	81.5	73.5	130.6	102.7	97.0
Target Identif.	Mean	504.4	516.9	478.7	500.1	499.9
	S.D.	91.1	64.0	104.1	93.9	84.8
Problem Solving	Mean	535.4	493.3	471.3**	499.5	500.5
	S.D.	60.4	58.3	75.9	73.6	67.4
Mental Arith.	Mean	525.5	497.0	477.4	502.6	497.4
	S.D.	66.4	72.8	99.3	88.0	78.0
Tracking	Mean	523.4	530.0	446.6**	502.4	497.6
	S.D.	78.5	107.6	72.2	99.3	91.1

* $p < .05$
** $p < .01$

Table 3. Main Effects of Period and Workload for Overall Composite Scores and Composite Scores for Individual Tasks

		PERIOD			WORKLOAD			
		1	2	3	1	2	3	4
Overall	Mean	500.5	497.1	503.5*	-	-	-	-
	S.D.	51.9	54.4	48.0				
Green Lights	Mean	500.2	495.3	504.5	526.7	488.0	511.5	473.8**
	S.D.	98.0	104.7	96.8	92.2	105.1	87.3	105.5
Red Lights	Mean	501.7	497.8	500.5	519.3	490.1	515.8	474.8*
	S.D.	95.2	110.8	92.9	82.7	112.8	77.6	114.1
Meters	Mean	494.2	500.0	505.5	535.2	492.0	519.4	453.5**
	S.D.	123.8	99.7	68.0	24.5	75.4	41.8	167.6
Target Identif.	Mean	507.7	492.9	499.4	530.3	469.7	-	- **
	S.D.	82.9	99.3	84.6	69.4	96.7		
Problem Solving	Mean	494.0	497.2	508.9**	-	505.1	-	494.9*
	S.D.	70.5	75.4	64.5		66.9		73.7
Mental Arith.	Mean	495.7	495.7	508.6*	-	-	516.9	483.1**
	S.D.	83.0	92.1	72.5			67.3	93.4
Tracking	Mean	506.9	498.4	494.7**	-	-	541.0	459.0**
	S.D.	100.8	93.3	91.1			95.5	75.4

* $p < .05$
** $p < .01$

Table 4. Interaction of Age with Workload for Each Task of the MTPB

Task	Age		WORKLOAD 1	2	3	4
Green Lights*	20-29 yr	Mean	555	548	545	536
		S.D.	93	66	75	76
	40-49 yr	Mean	552	514	533	492
		S.D.	52	85	62	82
	60-69 yr	Mean	472	405	456	397
		S.D.	99	99	92	100
Red Lights*	20-29 yr	Mean	504	514	512	504
		S.D.	123	80	100	69
	40-49 yr	Mean	533	518	535	500
		S.D.	56	59	33	72
	60-69 yr	Mean	518	439	500	422
		S.D.	44	154	80	157
Meters*	20-29 yr	Mean	535	517	525	494
		S.D.	29	37	36	113
	40-49 yr	Mean	539	501	524	455
		S.D.	9	38	26	94
	60-69 yr	Mean	532	456	509	412
		S.D.	15	82	36	255
Target Identification*	20-29 yr	Mean	524	483	-	-
		S.D.	91	86	-	-
	40-49 yr	Mean	536	499	-	-
		S.D.	58	64	-	-
	60-69 yr	Mean	531	429	-	-
		S.D.	51	118	-	-

Task	Age	WORKLOAD 1	2	3	4
Problem Solving	20-29 yr	-	538	-	533
		-	55	-	65
	40-49 yr	-	497	-	488
		-	65	-	50
	60-69 yr	-	481	-	465
		-	66	-	84
Mental Arithmetic	20-29 yr	-	-	538	515
		-	-	58	72
	40-49 yr	-	-	511	485
		-	-	62	80
	60-69 yr	-	-	505	455
		-	-	76	113
Tracking	20-29 yr	-	-	560	485
		-	-	73	65
	40-49 yr	-	-	576	480
		-	-	103	90
	60-69 yr	-	-	486	409
		-	-	81	32

*Interaction significant at the $p < .01$ level

Three other interactions were statistically significant, as shown in Table 5. The interaction of age with time period was significant in the tracking task ($p < .01$). Tracking performance declined over the three periods of a session in the 20-29 yr and 40-49 yr groups, but was maintained at a fairly constant level in the 60-69 yr group, although performance in the latter group was greatly inferior to tracking performance of the younger groups. The interaction of altitude with time period was statistically significant ($p < .05$) in the case of mental arithmetic although the changes in performance with time were small compared to those effects discussed above involving age. With the exception of Period 2, performance at ground level was superior to performance at 3,810 m. No other significant interactions of altitude with other variables were found.

The interaction of time period with workload was statistically significant in the case of the monitoring of meters. That interaction indicates that performance in Workloads 1 and 2 did not vary over the three periods of a session while performance was highest in Workload 3 at the second hour of the experimental session and highest in Workload 4 at the third hour of the session.

Discussion

Performance of MTPB tasks generally decreased with increasing age, with the exception of the monitoring of red lights and in tracking; in those two tasks, performance was highest in the 40-49 yr age group. Performance in the 60-69 yr group was consistently lowest in all tasks. An age-related decline in performance is consistent with findings of the single- and dual-task studies when workload stress was involved, as discussed above.

The most important finding of the present study was the significant interaction of age with workload in the performance of several component tasks of the MTPB. Increasing workload generally caused a decrease in performance in all age groups, but the amount of decrease was greater as age increased. This trend was statistically significant in all monitoring tasks, and most probably reflects the lower priority given the monitoring tasks relative to the other tasks; including mental arithmetic, target identification, problem solving and tracking, which demanded greater activity and cognitive resources for performance. The greater sensitivity of the monitoring tasks to workload in older subjects may indicate a decrease in residual attention at higher workloads for older subjects. It should also be noted that the trend of greater detrimental effect of increasing workload in older subjects also occurred in several of the more "active" tasks: problem solving, mental arithmetic, and target identification. The interaction of age with workload was of lesser magnitude in these active tasks, but was statistically significant in the case of target identification. Workload might have had a significant interaction in other active tasks if they had been presented in a wider range of workload conditions.

The consistent appearance of age-related effects of workload in performance of MTPB tasks in subjects selected for health and pulmonary function, is similar to the effect of increasing workload in pilots which

Table 5. Other Significant Interactions

MENTAL ARITHMETIC

	Period 1	Period 2	Period 3
Ground Level	503	491	517
3,810 m	442	503	503

TRACKING

		Period 1	Period 2	Period 3
Age	20-29 yr	538	512	517
	40-49 yr	537	529	519
	60-69 yr	444	453	445

METERS

		Period 1	Period 2	Period 3
Work-load	1	538	532	535
	2	495	489	490
	3	520	579	520
	4	426	459	476

Szafran found with a dual task situation (24,25). This finding of age sensitivity in MTPB performance suggests that the MTPB may be a useful tool in evaluations of a variety of biomedical factors in the aviation environment which may interact with age. Such factors may include fatigue due to sleep deprivation, cumulative sleep deprivation, and work-shift changes which are planned for study in this laboratory.

In the present study, complex performance measured over a 3-h experimental session did not reveal any important time-related changes in overall performance scores. Significant effects of time period were observed in individual task scores only in the cases of problem solving and mental arithmetic, in which performance improved in the third hour, and in tracking, in which performance decreased in successive hours of the session. The opposite trends in these tasks cancelled each other in the overall index of performance. These findings suggest a reciprocal change with time in the relative priorities among the three tasks. No loss of residual attention seems to have occurred with time since monitoring performance did not decline over the course of the 3-h session.

A mild simulated altitude of 3,810 m had no important effects on performance in the present experiment in any age group. This contrasts with the finding of a detrimental effect of a 3,810 m simulated altitude as compared to ground level in a previous experiment in this laboratory which also involved time-shared MTPB performance (13). The present lack of an altitude effect is unexplained in light of the previous positive finding, but it suggests that if effects of the mild 3,810 m altitude exist, they are small and variable.

Findings concerning the relation of age to heart rate during MTPB performance and the interaction of age with altitude in heart rate measurements are in general accord with findings in the literature. Mean heart rate for a 3-h experimental session increased at simulated altitude in the 20-29 yr and 40-49 yr groups of the present study, but decreased slightly in the 60-69 yr group. McFarland (19) found a similar pattern in his studies of the age/altitude interaction. The agreement of present findings with his, regarding heart rate, suggests that our method of altitude simulation was effective. The failure to observe a performance deficit at the 3,810 m simulated altitude is, therefore, not likely due to our method of simulating altitude.

The effective altitude in pressurized air carrier aircraft is less than the 3,810 m altitude simulated in this study, usually less than 2,438 m (8,000 ft). The present finding of no significant effect of the higher 3,810 m altitude on performance in any of the three age groups, therefore, provides some support for the use of aircraft simulators without simulation of cabin altitude in future studies. It should be noted, however, that some stressors such as sleep deprivation may interact with mild altitude as suggested by McFarland (20). Aircraft simulators typically do not have altitude simulation facilities. Should the simulation of altitude be required in future simulator studies, the use of special gas mixtures breathed through standard aviation face masks could be considered for simulation of mild altitude hypoxia.

Epinephrine excretion rates have often been associated with arousal and, hence, performance; arousal hypotheses have been used to explain age effects in performance (18). Although epinephrine excretion rates were highest in the 20-29 yr group which had highest performance, rates were not lowest for the 60-69 yr group which had the lowest level performance among the three age groups. Epinephrine excretion rates were also significantly higher at the simulated 3,810 m altitude.

The significant main effect of age on norepinephrine excretion rates, as with epinephrine, reflected the lower rates in the 40-49 yr group. Norepinephine excretion rates increased greatly at altitude in the 60-69 yr group, but decreased at altitude in the younger groups. There was no apparent association of performance with the excretion rates of epinephrine, norepinephrine, or 17-ketogenic steroids.

The effects of workload on catecholamine excretion rates could not be assessed in the present research design because all workload conditions occurred in each session and excretion rates could only be measured for the whole session. It may be useful in future research to evaluate the relation of age and workload to such biochemical responses in order to seek clarification of the complex relation of biochemical and performance measurements.

In healthy subjects, complex (time-shared) performance of flight-related tasks decreased with age. Age related performance decrements occurred in monitoring tasks, information processing tasks, and a task measuring psychomotor coordination. Differences occurring as a function of age were evident predominantly at moderate and high workload levels. Physiological and biochemical responses had little relation to performance.

Implications for future research concerning the relation of age to actual flight performance which may be conducted are as follows: 1) These findings suggest that age-related decrements may occur in a number of important flight related psychological functions and have adverse effects on flight performance, but these decrements may not be revealed unless the pilot experiences moderate or high workload levels; 2) Secondary monitoring tasks may be particularly useful in studies of the relation of age to performance of pilots in operational or simulated operational situations; 3) A synthetic work situation such as the MTPB may be useful and cost-effective for preliminary evaluation of a variety of aviation-related stressors which may interact with age; 4) Possible sex differences in the relation of age to performance should be evaluated.

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